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<b>(21) International Application Number:</b> PCT/US99/19694 <b>(22) International Filing Date:</b> 31 August 1999 (31.08.99)  <b>(30) Priority Data:</b> 60/097,830 31 August 1998 (31.08.98) US  <b>(71) Applicant (for all designated States except US):</b> DIGITAL OPTICS CORPORATION [US/US]; Suite J, 5900 Northwoods Parkway, Charlotte, NC 28269 (US).  <b>(72) Inventors; and</b> <b>(75) Inventors/Applicants (for US only):</b> TE KOLSTE, Robert [US/US]; 2320 Belvedere Avenue, Charlotte, NC 28205 (US). KATHMAN, Alan, D. [US/US]; 4700 Lone Tree Lane, Charlotte, NC 28269 (US). JOHNSON, Eric, G. [US/US]; 5721 Whitegate Lane, Charlotte, NC 28269 (US). FELDMAN, Michael, R. [US/US]; 3117 Lakewood Edge, Charlotte, NC 28269 (US).  <b>(74) Agent:</b> MORSE, Susan, S.; Jones Volentine, L.L.P., Suite 150, 12200 Sunrise Valley Drive, Reston, VA 20191 (US).		<b>(81) Designated States:</b> AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).  <b>Published</b> <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>
<b>(54) Title:</b> DIFFRACTIVE VERTICAL CAVITY SURFACE EMITTING LASER POWER MONITOR AND SYSTEM		
<b>(57) Abstract</b>  A power monitor for a light emitter emitting from a single face creates a monitor beam by deflecting a portion of the application beam and further manipulating the monitor beam to allow more efficient use of the monitor beam. For example, the monitor beam may be collimated to allow an increase in spacing between the light emitter and a detector for sensing the monitor beam. Alternatively or additionally, the monitor beam may be focused to allow use of a smaller detector and of a smaller percentage of the application beam. The diffractive element deflecting the beam may be either transmissive or reflective. The additionally manipulation of the monitor beam may be provided by the same diffractive element which deflects the beam, which is particularly useful when the diffractive element is reflective, and/or by additional optical elements.		

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## DIFFRACTIVE VERTICAL CAVITY SURFACE EMITTING LASER POWER MONITOR AND SYSTEM

### Cross-references to Related Applications

The present application claims priority under 35 U.S.C. §119 to U.S. Provisional Application No. 60/097,830 filed on August 31, 1998, the entire contents of which are hereby incorporated by reference for all purposes.

5

### BACKGROUND OF THE INVENTION

#### Field of the Invention

The present invention is directed to monitoring power of a light emitting device, specifically for a diffractive power monitor for use with vertical cavity surface emitting lasers (VCSELs).

10

#### Description of Related Art

Light emitting devices such as VCSELs need some form of power control to maintain a constant output. Such control is typically automatically performed by measuring an output of a light emitting device during operation and using this measurement to control the power supplied to the light emitting device.

15

Such control may be easily achieved when the light emitting device to be controlled is an edge emitting laser because edge emitting lasers output light from two

ends thereof. Thus, one output may be used for the desired application, while the other output may be used for the power control.

In contrast, a VCSEL typically only emits light from one surface. Hence, any monitoring of the light must be from the same output as used for the desired application of the VCSEL. VCSELs are much cheaper and their surface emissions make them easier  
5 to integrate with other optical devices than the edge emitting lasers, so the use of VCSELs is very desirable.

Previous attempts to monitor the power of VCSELS typically involve splitting off of a portion of the output beam to use as a monitor beam. Examples of such  
10 configurations are disclosed in U.S. Patent Nos. 5,757,836 and 5,774,486. However, such splitting off obscures part of the beam which may affect the wavefront and imaging, and hence coupling, of the light. Further, if the intensity distribution changes, such as when there is a change in lasing mode, the monitored power may change in a way which does not represent the overall output power of the VCSEL.

15 Additionally, splitting off of the beam may require the output of the VCSEL to be increased in order to maintain the requisite power level while allowing detection. Previous uses of scattering the beam to create a monitor beam relied on reflection for directing the beam and did not provide an optimal signal to the monitor detector.

Further, previous scattering did not insure the entire beam was being monitored.

### SUMMARY OF THE INVENTION

The present invention is therefore directed to power monitoring which substantially overcomes one or more of the problems due to the limitations and disadvantages of the related art.

These and other object may be realized by monitoring power over a light beam to be used in an application. Such monitoring may be performed using a diffractive to separate a percentage of the beam to be used to form a monitor beam and detecting the power of the monitor beam.

These and other objects of the present invention will become more readily apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating the preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

### BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, aspects and advantages will be described with

reference to the drawings, in which:

FIG. 1a and 1b are side views of an embodiment of the present invention incorporating a reflection diffractive element for forming a monitor beam;

FIG. 2 is a side view of another embodiment of the present invention incorporating a collimating transmission diffractive element for forming a monitor beam;

FIG. 3a and 3b are side view of systems incorporating the power monitor of the present invention;

FIG. 4 is a side view of an embodiment of the present invention incorporated with a can housing the light emitting device;

FIG. 5 is a side view of another embodiment of the present invention incorporating a collimating transmission diffractive element for forming a monitor beam; and

FIG. 6 is a side view of a power monitor of the present invention in conjunction with an array of light emitting devices.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

While the present invention is described herein with reference to illustrative embodiments for particular applications, it should be understood that the present invention is not limited thereto. Those having ordinary skill in the art and access to the teachings provided herein will recognize additional modifications, applications, and embodiments within the scope thereof and additional fields in which the invention would

be of significant utility without undue experimentation.

A configuration for monitoring power of an entire beam is shown in FIG. 1a. A light emitting device 10, e.g., a VCSEL or a light emitting diode, emits a light beam 15 to be used in a desired application. The light beam 15 impinges upon a diffractive element 20, preferably on a first surface 25 of a substrate 30. The diffractive element 20 is preferably a shallow diffractive structure, i.e., having phase depths of less than  $2\pi$ , the depth of which is determined by the wavelength of the light emitting device 10 and the desired efficiency of the diffractive element. Use of a shallow diffractive structure reduces the amount of light diffracted into the first order, i.e., into the monitor beam. Alternatively, this same effect may be realized by varying the width of the step heights so they are not equal to one another.

The diffractive element 20 transmits a majority of the beam into the zeroth or undiffracted order to form an application beam 40, while typically transferring a small percentage into other orders, including a reflective order. In some embodiments, up to 50% of the light may be deflected into higher orders to form the monitor beam. Light transferred into the reflective order is across the entire light beam and forms a monitor beam 45. Since angles associated with a reflective order to be monitored, typically the first reflected order, are known, an appropriately positioned monitor 50, e.g., a photodetector, measures the power of the monitor beam 45 and the measured power is

then used to control the operation of the light emitting device 10 in a known manner. A surface 35 opposite the diffractive element may include additional optical elements 37, either diffractive, refractive or hybrid, for performing further optical functions on the application beam 40, such as collimating, focusing, and/or coupling the light into a fiber.

5       As an illustrative example, if the light 15 has a wavelength of 830 nm, a diffractive element having an eight level blazed grating made in fused silica was designed to have a total structure depth of approximately 2300Å. This depth was chosen so that approximately 90% of the light is transmitted into the zeroth order to form the application beam 40, approximately 2% of the light is reflected into the first reflected  
10       order to form the monitor beam 45, approximately 1.4% of the light is transmitted into the first transmission order, with the remainder of the light being transferred to higher orders in decreasing percentages.

15       In both Figures 1a and 1b, the diffractive element 20 also focuses the monitor beam onto the detector 50. The focusing of the monitor beam avoids VCSEL feedback encountered when a grating is used to simply scatter the light. Further, the focusing allows the detector to be smaller. In general, it is preferable that the diffractive optical element used in the present invention provides optical functioning, e.g., collimation, focusing, to the monitor beam, particularly when the diffractive optical element reflects the monitor beam so no other additional surfaces are available on which to provide an



optical element for further optical functioning to the monitor beam. Such a diffractive element is preferably a computer generated hologram.

As shown in FIG. 1b, additionally or alternatively, a transmission diffractive element for performing at least one of the further optical functions on the application beam 40 may be incorporated with the reflective diffractive element 20 to form a combined diffractive 22. As can be seen in FIG. 1b, the application beam 40 is converging after leaving the first surface 25 of the substrate 30. The incorporation may be achieved by multiplexing the transmission hologram for forming the transmission diffractive element with the reflective hologram for forming the reflective diffractive element, discussed below.

For a transmission hologram, the physical step height  $d$  needed to get a phase depth of  $\phi$  ( $\phi$ ) is:

$$d = \lambda * \phi / \{2\pi * (n-1)\}$$

where  $n$  is the refractive index.

For a reflection hologram, the physical step height  $d$  needed to get a phase depth of  $\phi$  ( $\phi$ ) is:

$$d = \lambda * \phi / (2 * 2\pi)$$

To get a phase depth of  $2\pi$ , the etch depth is  $\lambda/(n-1)$  for a transmission hologram and  $\lambda/2$  for a reflection hologram. Thus, depending on the refractive index of the

material, the reflection hologram may be much shallower than the transmission hologram for the same phase depth. When combining these two types of holograms, the transmittance functions for the reflection hologram and transmission hologram are multiplied, i.e., their phase functions are added together. However, the phase values for the two types of holograms are encoded differently in accordance with the above equations. For example, if the index  $n=1.5$ , then a phase depth of  $2\pi$  for the transmission hologram is  $2\lambda$ , four times greater than the  $\lambda/2$  for the reflection hologram. If sixteen levels are used to encode the transmission hologram, then the four shallowest levels will correspond to  $0$ ,  $\pi/2$ ,  $\pi$  and  $3\pi/2$  for the reflection hologram.

When the phase functions are added for sufficiently low index materials, the reflection hologram function will only be a small modulation on the transmission hologram function, since the depth of the reflection hologram is much shallower, so there is not a large effect of one function degrading the other. Indeed, when using a plurality of levels, often the shallower levels needed for the transmission hologram correspond to many of the levels needed for the reflection hologram. Of course, if needed, either one or both of the hologram could incorporate levels having phase depths in excess of  $2\pi$ .

An embodiment employing a transmission hologram for forming the monitor beam is shown in FIG. 2. The light emitting device 10 again outputs a beam of light which is incident on a substrate 30 having a first surface 25 and a second surface 35. The

diffraction element 55 on the first surface deflects some light 60 off to the side. As can be seen in FIG. 2, the diffraction element 55 also collimates the monitor beam. This additional optical functioning may be realized by simply adding the two transmission functions together. Such collimation insures more light will be delivered to the detector 50 and allows greater separation between the VCSEL and detector, since the monitor beam is no longer expanding.

The deflected light 60 is then reflected off of the second surface by total internal reflection if the deflection angle is sufficiently steep, i.e., exceeds the critical angle at the second surface interface, or by an appropriately placed reflector on the second surface, such as a patch of metal 65. The reflected beam 70 then returns to the first surface, where it is incident on another transmission hologram 72 which focuses the monitor beam 75 onto the detector 50.

Again, the second surface may include optical elements for performing further optical functioning on the application beam 40. In the example shown in FIG. 2, the further optical element 37 on the second surface 35 of the substrate 30 focuses the application beam 40 in order to couple the light into an optical fiber 78.

The another transmission hologram 72 for focusing the deflected light onto the detector may be omitted if the diffraction element 55 is designed to provide focus to the

deflected light beam. Such a design would eliminate the additional loss incurred if the light passes through another diffractive optical element having power. Further, as shown in FIG. 2, the deflected light may be reflected a plurality of times if the angle is appropriate or if reflectors 65 are provided on the first surface of the substrate. This increases flexibility regarding placement of the detector. Further, as discussed above in conjunction with the reflection diffractive, additional optical elements may be incorporated with the transmission diffractive to provide further optical functioning on the application beam 40, either on the first surface or the second surface of the substrate 30.

10 The entire system may be integrated as shown, for example, in FIG. 3a and 3b. When the light emitting device is directly attached to a glass substrate as shown in FIG. 3a, the configuration shown in FIG. 2 is preferred. In FIG. 3b, the light emitting device is attached to a second substrate 80 which is separated from the substrate by spacer blocks 85, resulting in sufficient room to use either power monitor configuration. For 15 either of these configurations, the integration may occur on a wafer level.

As an alternative to the use of substrates, the reflection diffractive element may be incorporated into a plastic or glass cap 90 which may go inside a can 95 housing the light emitting device as shown in FIG. 4. The cap forms a protective, potentially hermetic, seal for the light emitting device. The cap 85 may be made in many ways,

including injection molding.

Another configuration is shown in Figure 5. As shown therein, light from the VCSEL 15 impinges upon a diffractive element which both splits off a portion of the beam to form a monitor beam and collimates both the monitor beam and the application beam. Such collimation allows increased flexibility in placement of the detector 10, since the monitor beam is no longer expanding. Additionally, the diffractive element 55 may also be used to focus the monitor beam on the detector 50. Alternatively, a refractive element may be provided on a surface adjacent the diffractive element 55 to provide the focusing. When placed near each other, i.e., the elements are close enough that the deflection created by the diffractive element still allows the beam to be focused by the focusing element, the relative order of the diffractive element and the focusing element doesn't matter. Preferably, the two substrates used in Figure 5 are created and bonded together on a wafer level and then diced in order to form the optical system for both the monitor beam and the main or application beam shown therein.

15 An example of a configuration for monitoring an array of VCSELs is shown in Figure 6. A monitor detector is provided for at least one of the VCSELs. The at least one detector, typically a corresponding array of detectors, is positioned in the plane of the drawing and a front view of each VCSEL 10 with a corresponding detector 55 would look like Figure 5. Again, the monitor beam may be collimated and/or focused by the

diffraction element. This collimation and/or focusing is particularly important when monitoring more than one beam of the array in order to insure the monitor beams do not influence one another.

Another alternative to the use of substrates, when the light is to be coupled to a fiber, includes incorporating the diffraction element for forming the monitor beam in a rod attached to the fiber.

While typically the entire beam is to be used, if only part of the beam is used, the diffraction element may create the monitor beam only from the portion of the beam to be used in the application. For example, if coupling the light to a fiber, only the portion of the beam which will be delivered to the core region of the fiber may be monitored.

Although preferred embodiments of the present invention have been described in detail herein above, it should be clearly understood that many variations and/or modifications of the basic inventive concepts taught herein, which may appear to those skilled in the art, will still fall within the spirit and scope of the present invention as defined in the appended claims and their equivalents.

What is Claimed is:

1           1. A power monitor for monitoring power of a light emitting device outputting  
2           a light beam, the light emitting device having a single light emitting face, the power  
3           monitor comprising:

4           an optical system comprising at least two surfaces, said optical system supplying  
5           a functional light beam to an application;

6           a diffractive optical element on one of said at least two surfaces splitting off a  
7           percentage of the light beam to create a monitor beam;

8           another optical element on one of said at least two surfaces which performs  
9           further optical functioning on the monitor beam; and

10          a detector for measuring power of the monitor beam.

11          2. The power monitor of claim 1, wherein said optical system further comprises  
12          performing at least one optical function to the functional light beam.

1           3. The power monitor of claim 2, wherein said at least one optical function  
2           comprises focusing said functional beam into a fiber.

1           4. The power monitor of claim 1, wherein the diffractive optical element is a  
2           transmission diffractive deflecting a percentage of the light beam to form a deflected  
3           beam.

1           5. The power monitor of claim 1, wherein said another optical element  
2 comprising a focusing optical element focusing the monitor beam onto the detector.

1           6. The power monitor of claim 4, further comprising metal on a surface opposite  
2 the transmission diffractive element, said metal reflecting the monitor beam.

1           7. The power monitor of claim 1, wherein the light emitting device is a VCSEL  
2 array and said diffractive optical element and said detector are provided for at least one  
3 VCSEL in the VCSEL array.

1           8. The power monitor of claim 1, wherein all elements of said optical system are  
2 integrated onto a single substrate.

1           9. A power monitor for monitoring power of a light emitting device outputting  
2 a light beam, the light emitting device having a single light emitting face, the power  
3 monitor comprising:

4           a diffractive optical element creating a monitor beam from the light beam, the  
5 creating including both splitting off a percentage of the light beam and performing  
6 further optical functioning on the light beam; and

7           a detector for measuring power of the monitor beam.



1           10. The power monitor of claim 9, wherein the diffractive optical element is a  
2   reflective diffractive reflecting a percentage of the light beam to the detector.

1           11. The power monitor of claim 9, wherein the diffractive optical element is a  
2   transmission diffractive deflecting a percentage of the light beam to form a deflected  
3   beam.

1           12. The power monitor of claim 9, wherein the further optical functioning  
2   includes focusing the monitor beam onto the detector.

1           13. The power monitor of claim 9, wherein the further optical functioning  
2   includes collimating the monitor beam.

1           14. The power monitor of claim 9, wherein the light emitting device is a VCSEL  
2   array and said diffractive optical element and said detector are provided for at least one  
3   VCSEL in the VCSEL array.

1           15. A power monitoring system comprising:  
2       a light emitting device generating a light beam, said light emitting device having  
3   a single light emitting face;

4 an optical system comprising at least two surfaces, said optical system supplying  
5 a functional light beam to an application;  
6 a diffractive optical element on one of said at least two surfaces splitting off a  
7 percentage of the light beam to create a monitor beam;  
8 another optical element on one of said at least two surfaces which performs  
9 further optical functioning on the monitor beam; and  
10 a detector for measuring power of the monitor beam.

1 16. The power monitoring system of claim 15, wherein the diffractive optical  
2 element is a reflective diffractive reflecting a percentage of the light beam to the detector.

1 17. The power monitoring system of claim 15, wherein the diffractive optical  
2 element is a transmission diffractive deflecting a percentage of the light beam to form a  
3 deflected beam.

1 18. The power monitoring system of claim 15, wherein said another optical  
2 element focuses the monitor beam onto the detector.

1 19. A power monitoring system comprising:  
2 a light emitting device generating a light beam, said light emitting device having  
3 a single light emitting face;

4       a diffractive optical element creating a monitor beam from the light beam, the  
5       creating including both splitting off a percentage of the light beam and performing  
6       further optical functioning on the light beam; and  
7       a detector for measuring power of the monitor beam..

1       20. The power monitor of claim 19, wherein the diffractive optical element is a  
2       transmission diffractive deflecting a percentage of the light beam to form a deflected  
3       beam.

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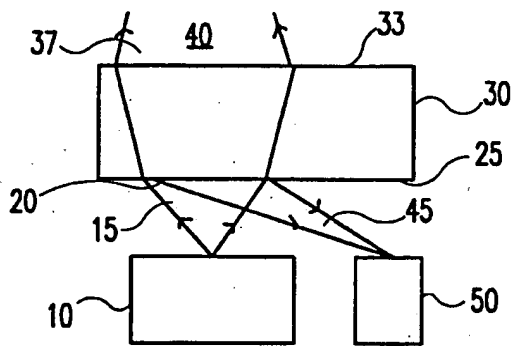


FIG. 1A

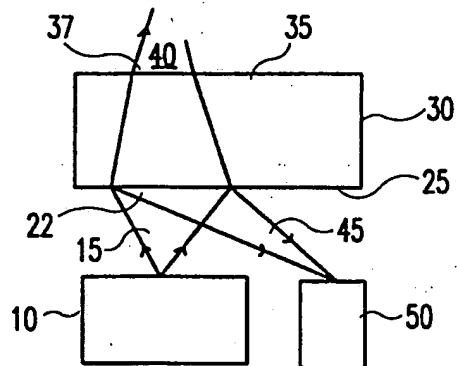


FIG. 1B

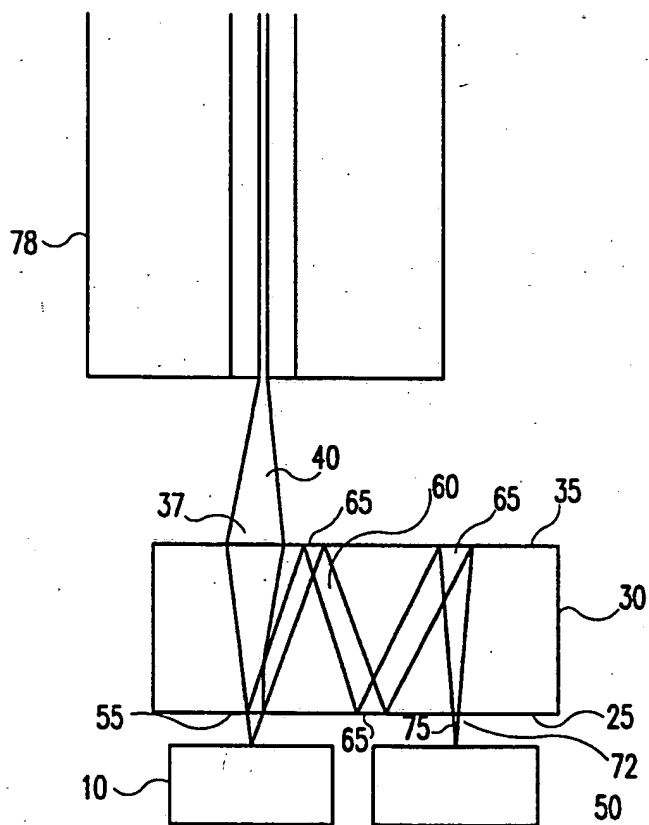


FIG. 2

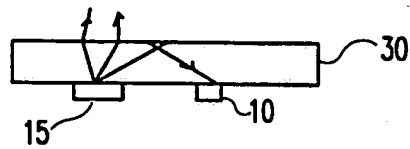


FIG. 3A

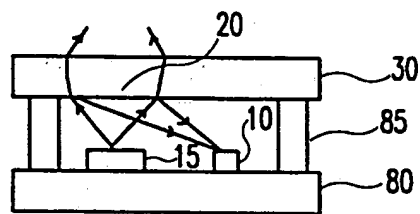


FIG. 3B

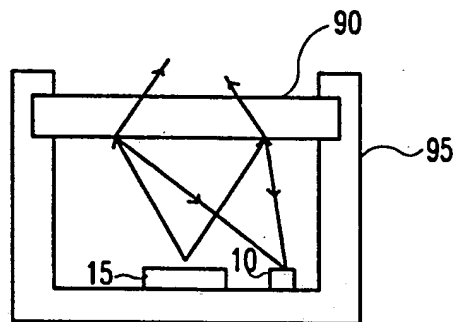


FIG. 4

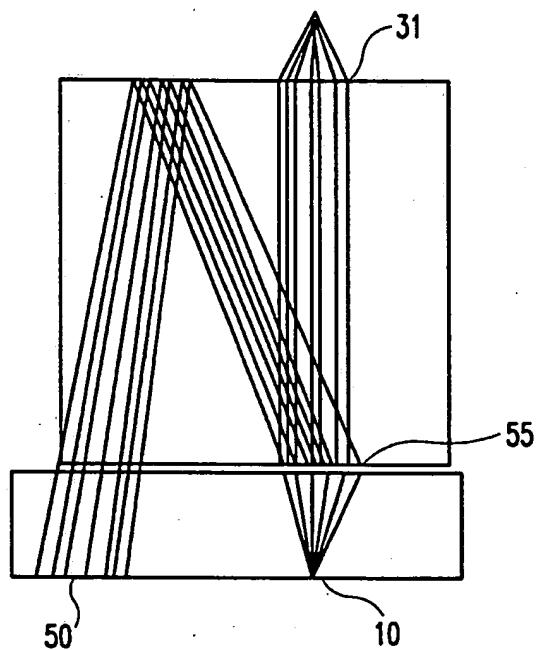


FIG. 5

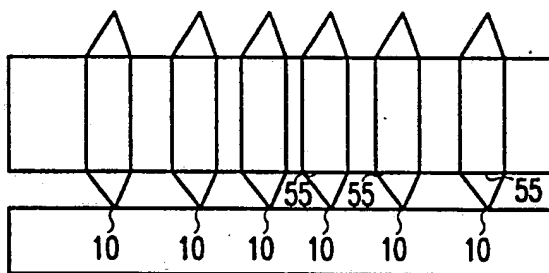


FIG. 6

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US99/19694

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G02B 6/26

US CL :385/39, 48, 88; 372/29

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 385/39, 48, 88; 372/29

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
None

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USPTO APS IEEE

search terms: laser and monitor

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y, P	US 5,832,156 (Strasser et al.) 03 November 1998 (03-11-1998), see entire document, especially figure 2.	1-20
Y	US 5,696,862 (Hauer et al.) 09 December 1997 (09-12-1997), see entire document.	1-20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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Date of the actual completion of the international search

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